

Electrostatic Charges in Weighing

Innovative Detection Solution

Summary

Various examples of routine laboratory work show that electrostatic charges exert forces on the material to be weighed and the weighing pan, thus causing significant falsification of measurement results. Following a brief introduction to the physics of static electricity, readers will find answers to questions about how electrostatic charges arise and dissipate, how Excellence analytical balances detect their presence, how large the measurement errors can be, and how those charges can be eliminated in order to obtain correct measurement results.

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1. Introduction

The following example describes a situation that routinely occurs in many laboratories:

Analytical balances are often used for dosing a defined quantity of powder into a glass flask in order to prepare a solution with a specific concentration.

For example, a 100ml volumetric flask is placed on the weighing pan. In normal conditions, there could be an electrostatic charge on the flask and, therefore a complementary charge is induced in the weighing chamber. This results in a net attractive force.

This net force could pull the flask down, making it appear heavier than it really is or push it upwards, making it appear lighter. Under dry air conditions, or climate controlled environments, such as the typical analytical laboratory, charges are more easily generated and lead to greater sources of error. If the balances displays a stable weight, the user proceeds by taring the balance and manually dosing a powder, which is a demanding and relatively time-consuming step.

A net force in either direction leads the user to dose too much or too little powder, leading to incorrect final solution concentrations. One classical example is that the charges on the tare vessel slowly discharge to the environment given time, which could cause the user to continually add too much powder, leading to even larger weighing errors. The concentration of the resulting solution is thus erroneously high, which may have a dramatic effect under some analytical measurement conditions, leading to Out of Specification (OOS) results, or even large amounts of retesting work.

Weighing a small quantity into a large glass or polymer vessel represents the classic use case where an electrostatic charge will significantly increase the error of the weighing result.

2. The physics of electrostatic charges – when are conditions especially critical?

2.1 Electrostatic forces

Coulomb's Law [1] states that electrical charges exert a mutual force F_E expressed as:

$$F_E = \frac{1}{4\pi\epsilon_0\epsilon_r} \frac{Q_1 Q_2}{r^2} \quad \text{or simplified to} \quad F_E = k_e \frac{Q_1 Q_2}{r^2} \quad [1]$$

Where: k_e is Coulomb's constant

Q represents individual charge on two separate objects

r is the distance between the objects

ϵ_0 & ϵ_r are absolute and relative dielectric constants

2.2 Electrostatic forces in weighing

An electrical charge on the balance or the material / vessel to be weighed causes electrostatic force. The balance measures the vertical component of this force and interprets it as a weight corresponding to a mass of Δm , given by:

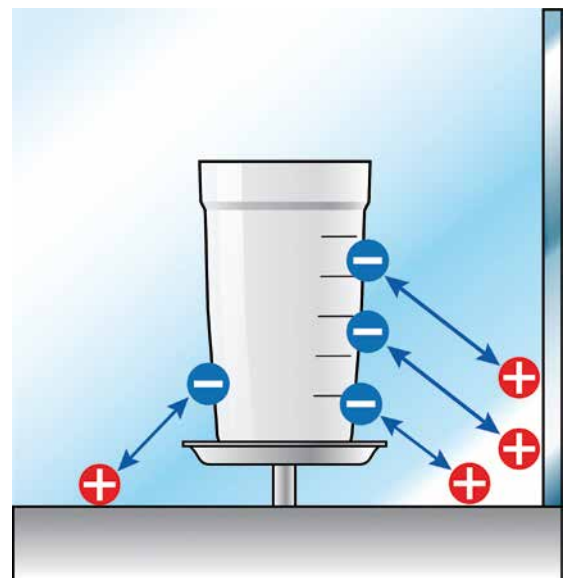
$$F_E = g \Delta m \quad [2]$$

in which g is the gravitational constant.

Thus, combining [1] and [2], and resolving for the mass change (or the total effect on the weighing result), the equation becomes:

$$\Delta m = \frac{1}{g} \left(k_e \cdot \frac{Q_1 Q_2}{r^2} \right) \quad [3]$$

Figure 1: Showing the field lines between a negative charge on the measuring flask and a complementary positive charge on the balance housing. The potential difference causes a force to be exerted between the balance and the material to be weighed. The vertical component of this force adds itself to the weight and thereby influences the weighing result.



How can an object (e.g. a weighing vessel) develop electrostatic charges? Friction is the most common way that electrostatic charges are generated. Everyone must surely remember the experiment in physics class where a glass rod is rubbed with a cloth and will then attract small pieces of paper or lift the hair away from your head.

¹⁾ Charges may also arise without the involvement of friction. Thus, merely separating two different materials (e.g. lifting a glass flask off a plastic surface) can suffice to produce a charge. The charge is stronger the further apart the respective materials are in the triboelectric series.

Typical laboratory actions that cause objects to become charged include using a cloth dry a glass beaker, touching a measuring flask through disposable gloves. Even unpacking a laboratory vessel from a plastic bag, or filling it with loose material is sufficient to generate measurable electrostatic charges.

Electrostatic charges dissipate over time. This happens fast with poorly insulating bodies, but can be very slow with bodies made from a good insulator. Most laboratory vessels and sundries are made of borosilicate glass, which happens to be an excellent electrical insulator. The same is true for practically all plastics used in the manufacture of many laboratory items. Even common window glass (sodium silicate glass) makes a good insulator under dry conditions.

2.3 Charge dissipation

The charged body's surface conductivity is one important factor affecting the dissipation rate of electrostatic charges: the higher the surface conductivity, the faster the electrostatic charges can drain away. Next to the material's intrinsic properties, surface conductivity also depends to a great extent on air humidity and the degree of surface contamination. Users need to exercise particular caution in winter when working in heated rooms where the air humidity is below 45%. Even so, many plastics remain excellent insulators even in very moist air. If repeated weighings of the same sample produce differing results, or if the measured value is seen to drift, this usually implies dissipation of electrostatic charges. The vertical component of the Coulomb force changes continually as a result, making precise measurement difficult.

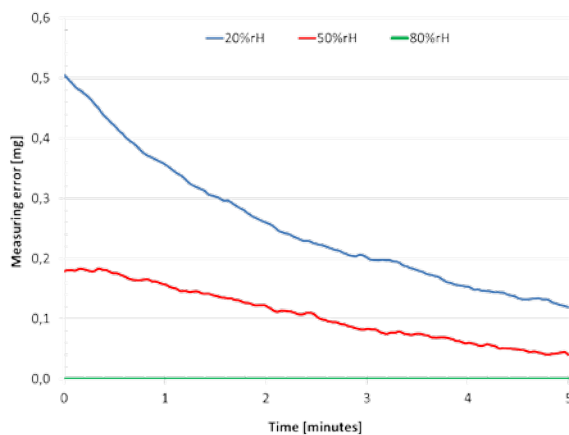
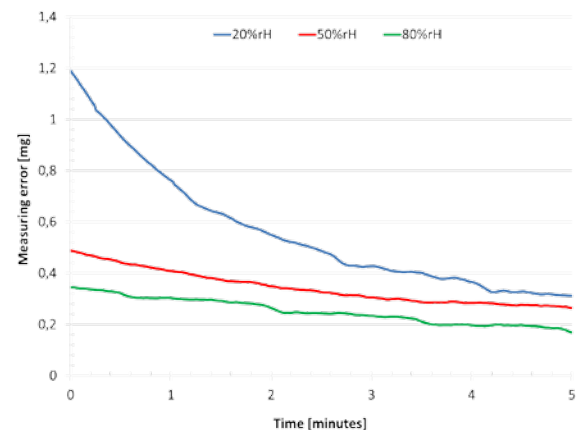


Figure 2: Typical dissipation over time of electrostatic charge from a 100 ml borosilicate glass flask. Falsification of the weight value thus lessens with passing time. A glass flask is unable to become charged at 80% relative air humidity.



The same graph, but this time for a weighing vessel made of PTFE. Even when air humidity is high, significant weighing errors are observed over a prolonged time period.

Contamination, relative humidity and the material involved thus influence the time constant of charge dissipation. Depending on conditions, a charge may take from a few seconds to several minutes to drain away. In a controlled, dry atmosphere where the relative humidity is 20% or less, charges on material to be weighed can persist over many hours.

3. Electrostatic forces and their effect on weighing accuracy

Experiments with weighing a sample contained in a plastic vessel show a measurement error in the order of a few milligrams; this is attributable to the Coulomb force F_E according to formula [1]. However, errors of up to 100mg may occur in some cases. Hence, major errors in measurement may occur when weighing small sam-

ples. These situations are often recognizable by drifting measurement readings and non-repeatability of the measurement result. This perturbation can generally be counteracted by adopting appropriate anti-static measures, such as an ionizer or letting the charge naturally dissipate. Yet there are cases where the problem is difficult or indeed impossible to notice – such as if a stable weight is achieved, with a net electrostatic force present.

In any circumstance, automatically detecting external effects to the weighing result due to electrostatic charges makes balance operation simpler and more dependable, as well as constituting an important step forward in weighing technology.

4. How Excellence analytical balances detect electrostatic charges

Integrated within the balance, beneath the grounded weighing pan, is a concentric electrode. An alternating square wave with amplitude of around 60V and a frequency of 1.2Hz is applied to it during the detection phase.

The positive half-cycle of the square wave generates positive charge carriers on the electrode. If the material to be weighed is free of charge carriers, no electrostatic forces due to formula [1] will arise; the weighing cell measures the true weight of the sample.

If the sample is negatively charged, there is a momentary attractive force between the negatively charged material to be weighed, and the electrode. The weighing cell registers the vertical component of this force, producing a result that exceeds the true mass. This case is illustrated in Figure 3a. The electrostatic field changes sign in the following half-cycle, due to negative charge carriers being generated on the electrode. Now there is mutual repulsion between the material to be weighed and the electrode (Figure 3b) and the measurement result becomes less than the effective mass. The potential measurement error is determined from the difference between the two values, using a correlation factor (Figure 4). Figure 4 shows measurements that illustrate this relationship.

With a positively charged sample, the forces are reversed.

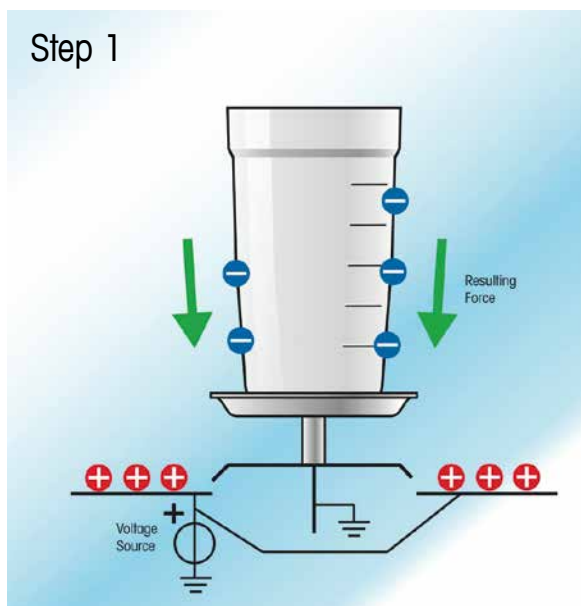


Figure 3a: There is an attractive force acting between the material to be weighed and the electrode. The vertical component of this force adds itself to the weight, thus increasing the measurement result.

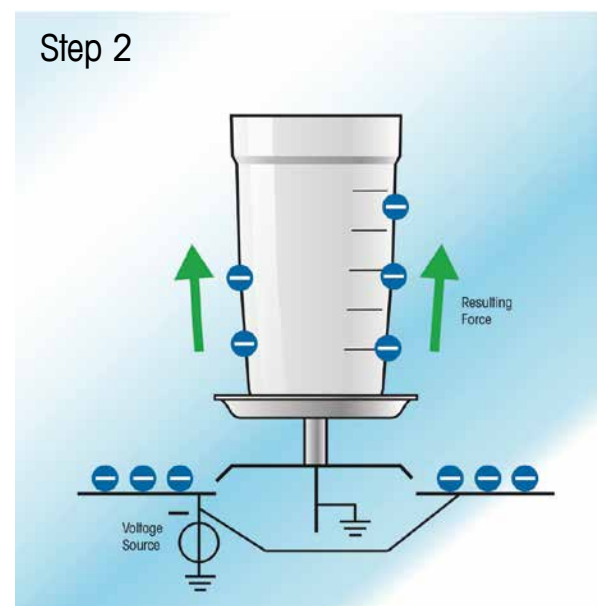


Figure 3b: There is a repulsive force acting between the material to be weighed and the electrode. The vertical component of this force adds itself to the weight, thus decreasing the measurement result. The difference between cases a and b is used to derive the weighing error caused by electrostatic charges

Intelligent signal processing employing lock-in or synchronous detection techniques improves the signal-to-noise ratio and suppresses interference. Charge sensing measures only at the exact excitation frequency of the charge generator. Thanks to an optimum choice of frequency, the measurement process takes only a few seconds and lies within the usual balance stabilization time, so it does not slow down the user's work.

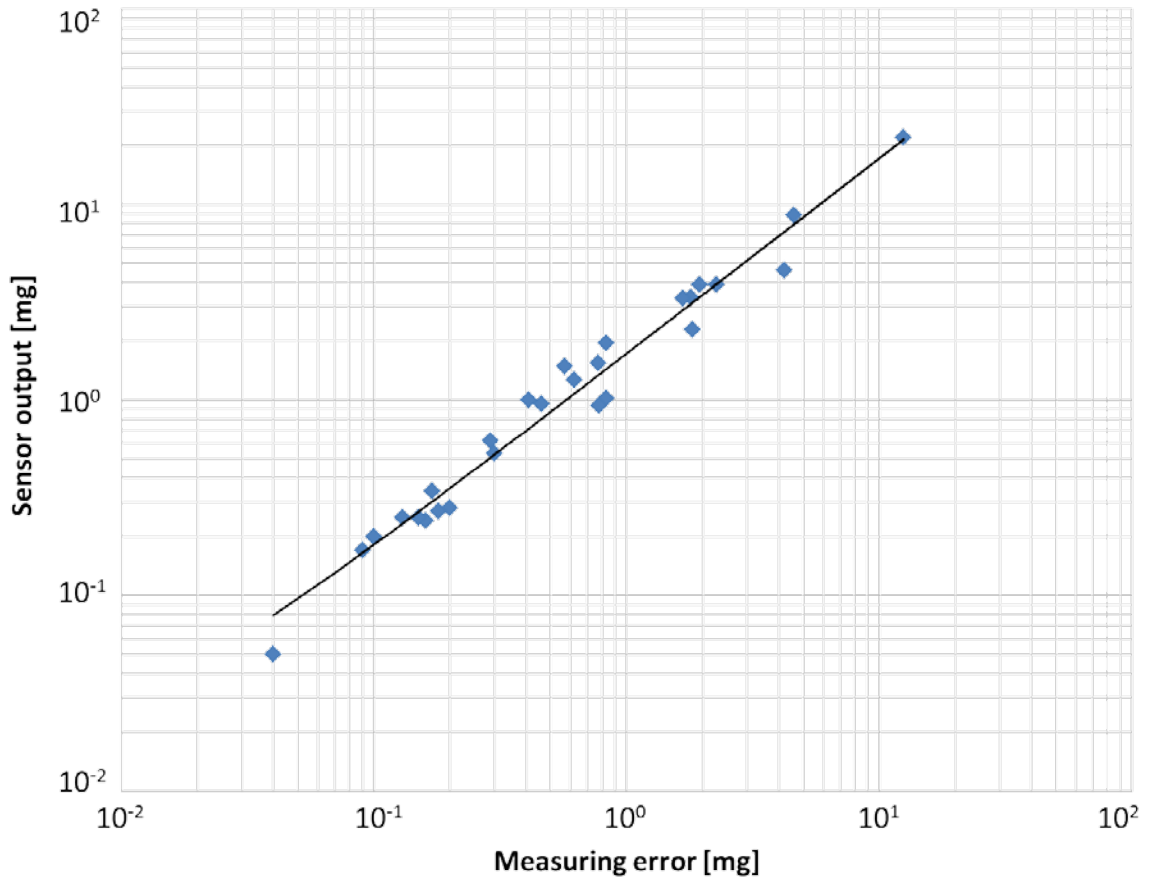


Figure 4: Measurements show good correlation between the true weighing error over several decades. The points represent measurements performed using a variety of weighing vessels placed at different positions on the weighing pan and carrying various levels of charge. The charge sensor is calibrated such that the true error does not exceed the indicated error.

Other methods for detecting whether a body is electrostatically charged do exist. However, they all have the disadvantage of being unable to estimate the extent by which the electrostatic charge influences the weight value. Formula [1] makes it evident that the mutual force between the two charges also depends on how far apart they are; hence the force is highly contingent on their spatial proximity. Only the measurement technique outlined here can cover this gap.

Compared with other approaches, this measurement technique is also immune to electromagnetic interference.

5. The new “StaticDetect™” function for users of Excellence balances

Excellence analytical balances automatically begin their electrostatic detection cycle when a sample is placed on the weighing pan, and warn the user if the material to be weighed is found to carry a charge. The user can select a detection threshold in grams. This additional step described in section 4 causes no delay to presentation of the measurement result.

A blue status indicator lights up while measurement is in progress. There are two possibilities afterwards:

- The status indicator switches off: the weight measurement is correct and not falsified by an electrostatic charge;
- The status display starts to blink: this provides a warning that a significant electrostatic charge has influenced the measurement result, and the terminal screen displays a warning showing the magnitude of the error. Appropriate anti-static measures (see section 6) need to be taken to ensure accuracy.

6. Measures to avoid weighing errors caused by electrostatic forces

1) Prevent build-up of electrostatic charge:

- Use materials that are electrically conductive, or incorporate anti-static treatments;
- When handling, avoid contact between dissimilar materials (according to the triboelectric series);
- Connect contact surfaces electrically to ground;
- Raise the air humidity. Electrostatic charges frequently occur during the winter season in heated (dry) rooms. In air-conditioned rooms, setting the air conditioning plant accordingly (45-60% rel. humidity) may provide a remedy.

2) Reduce the forces produced by electrostatic charges:

- Electrically screen the material to be weighed inside a Faraday cage on the weighing pan, e.g. using the well-proven "ErgoClip" tare vessel holder from METTLER TOLEDO;
- Use a smaller tare vessel;
- Place material to be weighed centrally on the weighing pan, and ensure the minimum possible protrusion beyond the rim;
- Use a light, electrically conductive underlay to increase the distance between the tare vessel and the surface of the weighing area.

3) Dissipate electrostatic charges:

- Ionize the air using an anti-static kit from METTLER TOLEDO. All METTLER TOLEDO anti-static kits use Alternating Current (AC) ionizers for the best possible discharging of vessels and samples, without disturbing air currents.
- Use anti-static pistols, although not all commercially available products are not truly effective;
- Use radioactive sources (polonium-210, weak x-ray sources, etc.) to ionize the air, although such measures are subject to country-specific regulations;
- Ground the balance (and hence the weighing pan). All METTLER TOLEDO balances fitted with three-pin power plugs are automatically grounded.



Figure 5: A metal basket serves as a tare vessel holder for reagent glassware and tubes, while optimally shielding electrostatic charges.

Conclusion

Automatically detecting perturbation due to electrostatic charges makes balance operation simpler and more dependable, as well as constituting an important step forward in weighing technology. Because the existing weighing cell is used for detection, the balance can not only recognize electrostatic charges on the material to be weighed, but also provide details about the size of the measurement error by taking into account the effective geometry. This markedly increases the assurance that a user is working with accurate and reliable weighing results.

The user should employ established remedies for suppressing electrostatic charges on the material to be weighed or on the tare vessel (refer to white paper on anti-static measures), e.g. reducing the object size and surface resistance, screening from electrical fields ("ErgoClips"), increasing the relative air humidity, or using dedicated ionization equipment.

References

Weighing the Right Way

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Effects of electrostatic charges on weighing: measures for avoiding errors and problems

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